Purdue University
Purdue e-Pubs

International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

1986

New Designed System of Computer Programs to Generate, Evaluate, Check-up, Manufacture and Measure Automatically Fairs of Screw Rotors of Refrigerating Compressors

S. Nowotny

NEW-DESIGNED SYSTEM OF COMPUTER PROGRAMS TO GENERATE, EVALUATE, CHECK UP, MANUFACTURE AND MEASURE AUTOMATICALLY PAIRS OF SCREW ROTORS OF REFRIGERATING COMPRESSORS

O. HEINEMANN
A. KOSSLER
S. NOWOTNY
VEB Kombinat ILKA Luft- und Kältetechnik Dresden
Stammbetrieb für Forschung und Technik
Dresden (German Democratic Republic)

1. INTRODUCTION

Screw compressors have found wolrdwide application during the last two decades especially as concerns refrigerating machines. Starting at a range above of 100 m^3/h of theoretical displacement but now also to a greater extend below 100 m^3/h they are used mainly with double screw rotors.
The main reasons for their steadily growing application are the smaller number of individual parts, and their longer life if we compare these compressors with reciprocating ones.

The use of computers in the process of research and development as well as automatic manufacturing and production control especially of pairs of screw rotors has contributed and will probably to do so towards improving the quality of these compressors.
The following exposition will give more details about the utilisation of computers especially the computer-aided design in order to generate, to calculate, to check up, to machine and measure pairs of screw rotors of refrigerating compressors.

2. THE APPLICATION OF SCREW COMPRESSORS IN THE REFRIGERATION INDUSTRY IN THE GERMAN DEMOCRATIC REPUBLIC

Screw compressors have been manufactured in the GDR since 1970. At first licenced by the Swedish company SRM they have steadily been developed and are now manufactured according to our own design. They are available in 5 different sizes from 315, 450, 900, 1800 to 2500 m^3/h of theoretical displacement as concerns one-stage open-type compressors, and 315/900, 900/2500 m^3/h as concerns two-stage open-type compressors. The assortment of different models is expected to be increased in steps by adding units of 40, 56, 80, 112, 160 and 224 m^3/h.

To meet the growing demand concerning energy efficiency, reliability and quality of these screw compressors in the future, CAD has been used at the stage of research and development, design, preparation of manufacturing, checking and quality control. Figure 1 shows its applications:

GENERATION OF THE PROFILES
- mathematical modelling of the profile geometry
- simulation of the behaviour or screw rotor pairs
- thermodynamic and mechanics calculation

PREPARATION OF MANUFACTURING
- calculation of the tool geometry from screw rotor geometry
- simulation of errors resulting from manufacturing, and analysis of various techniques of manufacture
- elaboration of control strategies to control CNC-machine tools to manufacture screw rotors and tools

MEASURING TECHNIQUE AND QUALITY CONTROL
- computer-assisted aqusition and processing of measured data
- computer-assisted quality control and handling of theory of errors

Fig. 1 - Survey of the application of CAD at screw rotor development

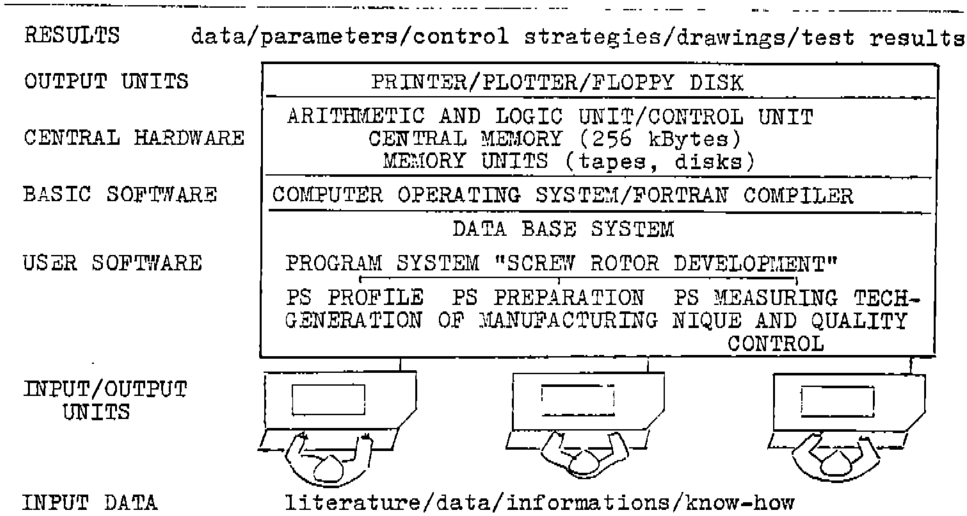


Fig. 2 - General view of the solution of man-machine communication

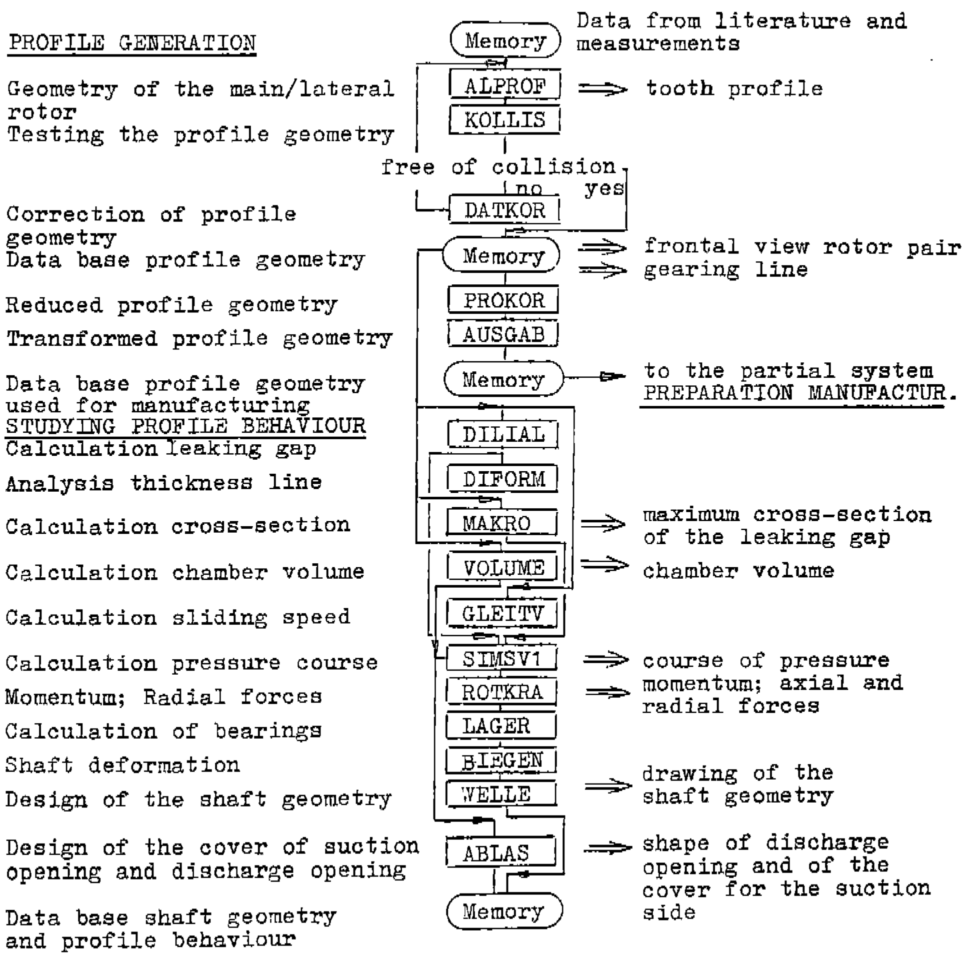


Fig. 3 - Schematic view of the partial system "PROFILE GENERATION"

In order to perform the tasks mentioned in Fig. 1 it has been taken into consideration that the whole task has to be solved via man-machine-communication. Approximately 30 individual programs are organised via a computerised data handling system which ensures that the input and output data will be stored througout the computing process on the one hand and that on the other hand it can be reused at any time. Special plotting programs enable the results to be represented graphically. Fig. 2 shows the general principals of man-machine communication.

3. DESCRIPTION OF THE FUNCTIONING AND OF THE GENERAL CONTENTS OF COMPUTER PROGRAMS

3.1 THE GENERATION OF THE PROFILE

Fig. 3 shows the partial system PROFILE-GENERATION. The basis to start the computation is the data base of the profile coordinates of one tooth (cog) of the main or the lateral rotor. The number of teeths, the wheel base and the different diameters of the rotors are considered to be input data. Profiles of an asymmetric shape are computed, for instance on a basis of a sequence of points constituting parts of geometrical curves, shaped in such a manner, that a minimum gap between them is guaranteed on the one hand, and that manufacturing can be ensured on the other hand.

The profiles of the main and the lateral rotors are described by coordinates and tangents of these coordinates in the form of a socalled standard representation. In order to describe a tooth (cog) up to 250 pairs of coordinates x and y are used. See Fig. 4.

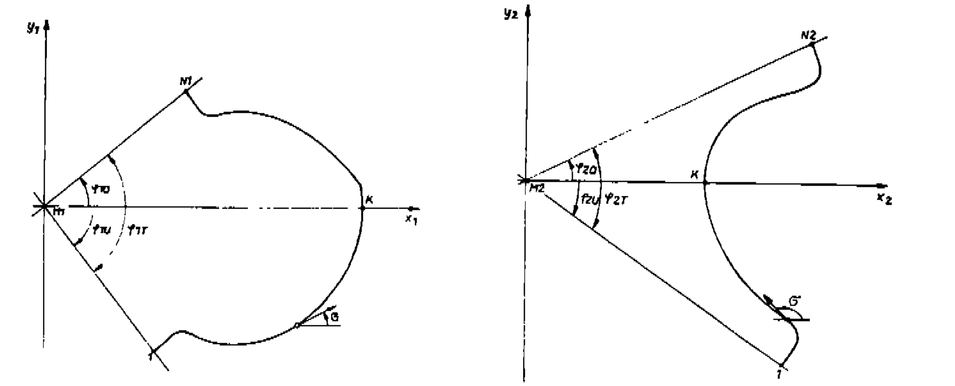


Fig. 4 - Definition of the standard representation of the main (a) and the lateral (b) rotor

The following additional conditions are taken into consideration:

- the point K at y=0 has the greatest wheel base as concerns the main rotor (male) and the smallest wheel base regarding the lateral rotor (female)
- the points 1 and N form the angle of the toots partition φ_{1T} for the main rotor and φ_{2T} for the lateral rotor
- normalised vectors of the tangents point towards the sequence of points.

By introducing the length of the rotor and the tooth lead into the system of coordinates the three-dimensional description is guaranteed. The computer program called ALPROF calculates the profiles of the main and lateral rotors by means of the coordinates of the appropriate profile of the lateral and main rotor respectively. Fig. 5 shows the cross-section of the pair of rotors together with the appropriate geometrical data. The computer program works without any iteration in accordance with the condition of the toothing. Sharp bends

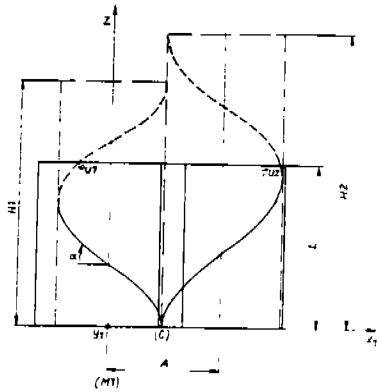
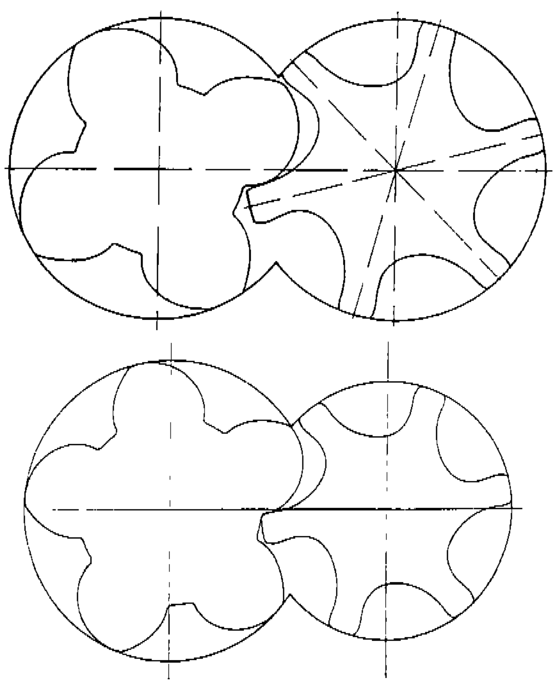


Fig. 5 - Representation of a screw pair at cross-sectional view

within the profile contour are detected as dots which have two tangents and are treated us such. On the other hand dots which show a distance too large are interpolated automatically into the conjugated profile.

The profiles of the main and lateral rotor calculated by the program ALPROF are checked up by using the program KOLLIS which tests the profile geometry regarding intersections which may occur when the two corresponding coordinates of the profile are checked regarding a minimum distance of both moving dots. If the program KOLLIS shows small intersections the program DATKOR will be introduced in order to correct the appropriate data, which means, that the whole calculation will be repeated. Following this calculation the frontal view of the pair of rotors can be plotted for different angles of both rotors. See Fig. 6.



(a)

(b)

Fig. 6 - Screw pair at frontal view; standard representation, main rotor with 4 (a) and 5 (b) teeth

Using this calculation program the course of the gearing line of the main and lateral rotor is determined. Fig. 7 shows the gearing line with reference to the main rotor.

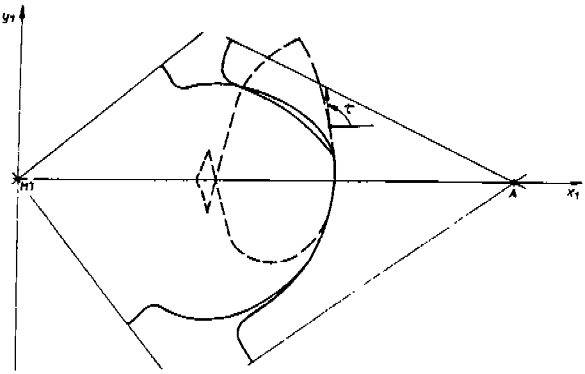


Fig. 7 - Screw pair with coordinates in the frontal intersection showing the gearing line with reference to the main rotor

Taking into account the set of data of the main and lateral rotors which are free of intersections, the program PROKOR is used to obtain a reduced profile geometry of the lateral rotor. The occurrence of free motion which results from this step ensures that the transmission of forces on the lateral rotor is carried out in a range of relatively low sliding speed. At the same time the coordinates of the profile are transformed into a representation which can be used for manufacturing. The data set prepared in this way can be used in the partial system PREPARATION OF MANUFACTURING.

After the partial system GENERATION OF PROFILES has handled the profile geometry in frontal view, the rotor wheels should now be designed and the behaviour of the rotor profile should be determined. For this it is now necessary to fix the length of the rotor, the tolerances to be reached during manufacturing, the tooth lead and the working conditions of the screw compressor. Using the program DILIAL the area of the leaking gap of the thickness line is determined. Another program which follows is called DIFORM. It makes it possible to make a close analysis of the thickness line and the appropriate shape of the leaking gap by varying the range of tolerances and the position of the flanke side.

In order to determine the opening of the leaking gap between the individual chambers of compression the program MAKRO calculates the maximum cross-section of a straight stream line which flows through this gap by varying the jet direction. This is probably the best method to approximate a perfect three-dimensional flow through the gap.

The program VOLUME is then used to determine the chamber volume by using the set of data of the main and the lateral rotor. Fig. 8 shows the chamber volume for two different lengths of the rotor versus the revolving angle Φ. The line below shows that between the suction and the discharge phase the pair of rotors has a period of transport of constante volume. The upper curve demonstrates an intersection between the process of suction and discharge.

The subprogram GLEITV determines the sliding speed of the selected pair of profiles.

Using the data achieved by calculating the thickness line (DILIAL), the blowing hole (MAKRO), the chamber volume (VOLUME), and the working conditions of the screw compressor which includes the refrigerant properties, the program SIMSV1 determines the course of pressure in the chamber, the refrigerating capacity and the driving performance.

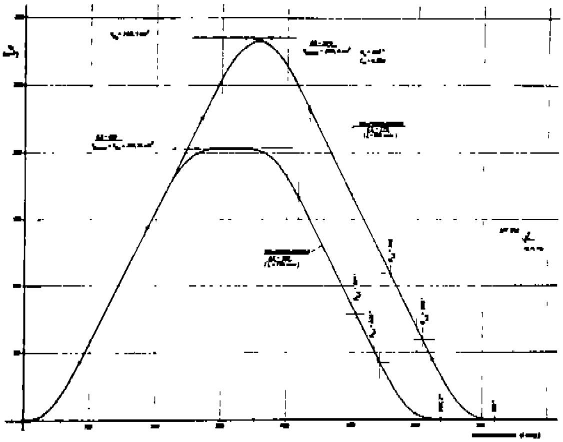


Fig. 8 - Chamber volume of screw rotors of different lengths

By means of the data of the course of pressure versus the revolving angle, the program ROTKRA enables us to calculate the momentum and the forces which influence the rotors. One obtains the radial forces for any individual point of working condition with respect to the main and lateral rotors and the distribution of the axial forces. With these data the calculation of the bearings and the simulation of the deformation of the shaft as a result of the forces can be made. With these results the geometry of the rotor is determined so that the drawing of the shaft can be carried out automatically.

The data of the volume function are used to calculate the shape of the discharge opening of the compressor case and the cover necessary for the suction side of the compressor with the aid of the program ABLAS.

The partial system of computer programs described here is a precondition for the preparation and a successful implementation of the design of a screw compressor on the basis of a newly developed system of profile geometry. The program system is intended to be used to obtain an optimum profile geometry to be used for special purposes by introducing and analysing new shapes of profiles, dimensions, number of teeths, ratio of the lengths of rotors, and the screw lead. Profiles using so-called spline-functions are being studied.

3.2 PARTIAL SYSTEM PREPARATION OF MANUFACTURING

The scheme and the utilisation of the partial system PREPARATION OF MANUFACTURING can be seen in Fig. 9. The program system is used to calculate the necessary coordinates of tools and of auxiliary resources for manufacturing the rotor profiles and to develop the computer programs for CNC-based manufacturing of tools.

The calculation starts with the shape of profile of the tooth gap of the main and the lateral rotor (see Fig. 4), which were determined by the partial system GENERATION OF THE PROFILE GEOMETRY.

The program system WZPROF is intended to solve the following tasks:

1. Technical preparation of the fore manufacturing of rotors (nominal profile in coordinates in the frontal intersection with an oversize for the final grinding)
2. Technical preparation of the final handling of the surface of rotors (nominal profile in coordinates in the frontal intersection without an oversize)

3. Technical preparation of the fore manufacturing of tools (tool profile with an oversize for the final grinding)
4. Technical preparation of the final handling of tools (tool profile without an oversize).

The program system takes the following machining techniques for rotors into consideration:

- milling
- grinding
- whirling
- hobbing

The program system includes the simulation of fitting between the workpiece to be machined (rotor) and the tool which is calculated in order to guarantee a manufacturing free of collisions.

In order to machine the tools and additional resources the program makes it possible to study the following machining techniques:

- CNC-grinding of profiles used to machine adjusters and templets
- CNC-erode used to machine templets and cutting tools
- CNC-profile turning used to machine adjusters and negative models of adjusters
- CNC-adjusting used to grind rotors
- drawing of templets used for optical copying techniques and for checking tools.

Based on uniformly structured data bases the introduction of other machining techniques and the linking with further control strategies for machine tools is possible without any trouble. The easy-to-handle use of the partial system PREPARATION OF MANUFACTURING is solved by computer-assisted guiding of the user (help files), and by a fully graphic representation of the calculated results (shape of profile, drawing of tools).

The profiles calculated for tools and additional resources are necessary precondition to utilise the partial system MEASURING TECHNIQUE AND QUALITY CONTROL. The partial system PREPARATION OF MANUFACTURING can also be used to determine further parts which are similar as screw rotors (extruders, gears, etc.).

The calculation of the tool profile is carried out by means of the trace of mesh between the tool and the workpiece. The precondition to calculate the trace of mesh can be defined as follows:

"The normale on the rotor surface at any point of the trace of mesh has to cross the tool axis".

From the condition of the trace of mesh as well the definition of the system of coordinates and parameters result the following input data which are necessary for the calculation method:

x_a; z_a - coordinates of the intersection profile of the axis

$\dot{x}_a$; $\dot{z}_a$ - components of the tangents on the intersection profile of the axis of the work piece

h - pitch of the rotor profile

γ - the angle between tool and workpiece axis

The mathematical description of the cutting conditions between the normal and the tool axis results in a transcendented equation which includes the unknown screw parameter φ. The solution of this equation is solved with the aid of a modified Newton procedure. The result will be:

x ; z - coordinates of the tool profile

$\dot{x}$; $\dot{z}$ - components of the tangents on the tool profile

In order to forework of the rotors and tools it is necessary to

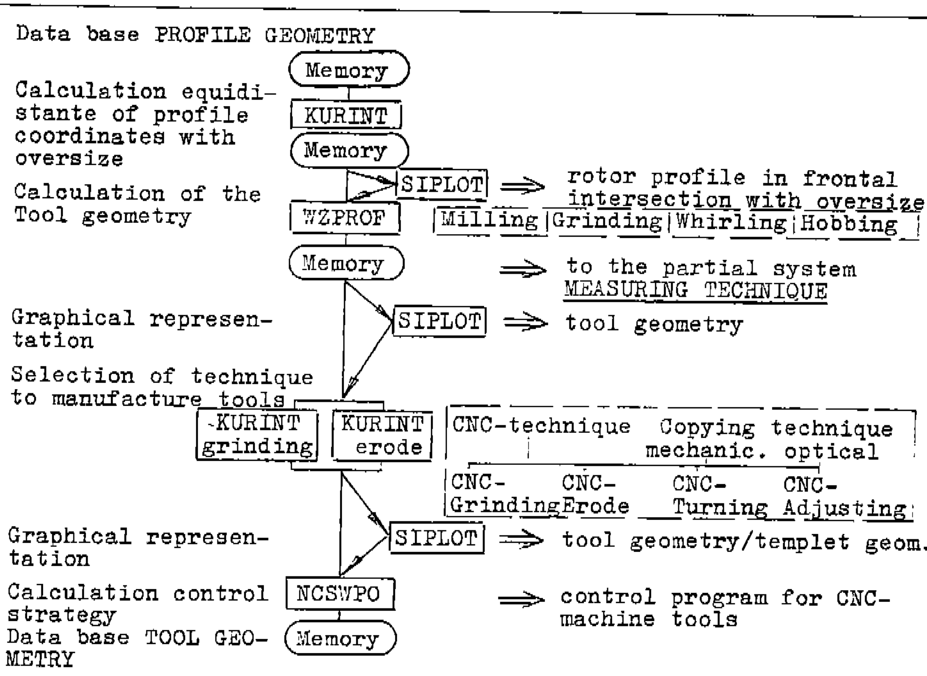


Fig. 9 - Schematic view of the partial system PREPARATION OF MANUFACTURING

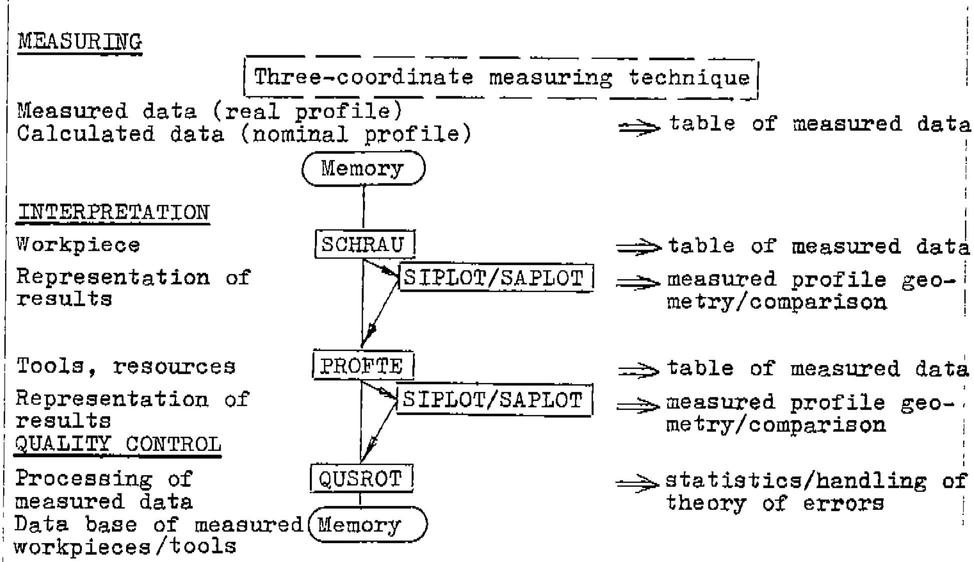


Fig. 10 - Schematic view of the partial system MEASURING TECHNIQUE AND QUALITY CONTROL

calculate an equidistant for the profile to be manufactured.

3.3 PARTIAL SYSTEM MEASURING TECHNIQUE AND QUALITY CONTROL

The introduction of an efficient measuring technique into a closed developing system of screw rotors is necessary if we take the following points of view into account:

- analysis of rotor machining to minimise of the deviations as a result of manufacturing
- analysis of the relations between deviations dimensions, shape and position, and of the working conditions of the compressor.

The preconditions for solving this task is a closed and uniform definition of the deviation of dimension, shape and position of rotors and tools, and an efficient measuring technique which ensures the checking of deviations with sufficient accuracy on the other hand. These are done with the aid by three coordinate measuring techniques in connection with a powerful computer program.

In order to interpret the measuring results including the elimination of systematic measuring errors the programs

SCHRAU - measuring of rotors
PROFTE - measuring of tools

have been developed.

Fig. 10 shows the structure and use of this program system. For using any of the multi-coordinate-measuring devices the following pieces can be measured by introducing the computer program:

- rotors with any profile geometry (even unknown profiles)
- tools with any profile
  - adjusters
  - whirling tools
  - hobbing tools
- inspecting-and additional resources
  - copying templets to manufacture tools
  - resources to manufacture rotors and tools.

In order to be able to measure rotors the coordinate measuring device should have one rotory axis at least.

The easy-to-handle program system has been made possible by a dialogue- and screen-oriented guiding of the user, through further information given to the user by means of help files, through a large-scaled choose of the measuring and data-handling algorithme, and last but not least through a closed graphical representation of the measuring results.

The computer program produces a data base on an external memory which can directly be used by the following programs. For further interpretation of results the following programs are realized:

- graphic representation of the measured profile (see Fig. 11) and the comparison between the calculated and the measured profiles (see Fig. 12)
- implementation of a data base for all results measured
- simulation of the behaviour of screw pairs measured.

The program systems described here can also be used for measuring and implementing any similar workpieces to be tested.

4. CONFIGURATION OF THE COMPUTER SYSTEM USED

The full system of computer programs has been developed and implemented on a computer system which can be compared with the machine PDP11. The central memory of the computer has a capacity of 256 kBytes. The computer is equipped witha sufficient periphery. The basic working system of the computer has to assist overlay technique.

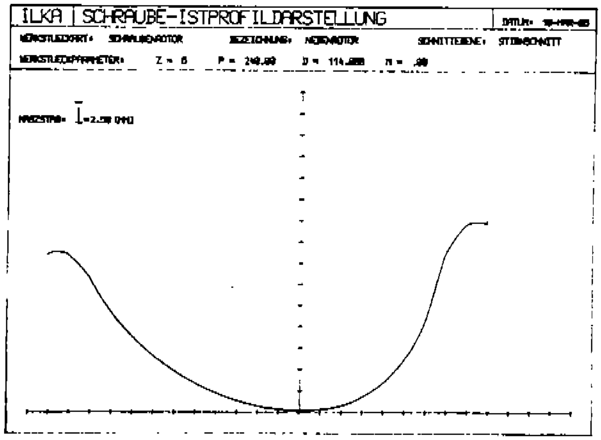


Fig. 11 - Graphic representation of the measured profile of the lateral rotor

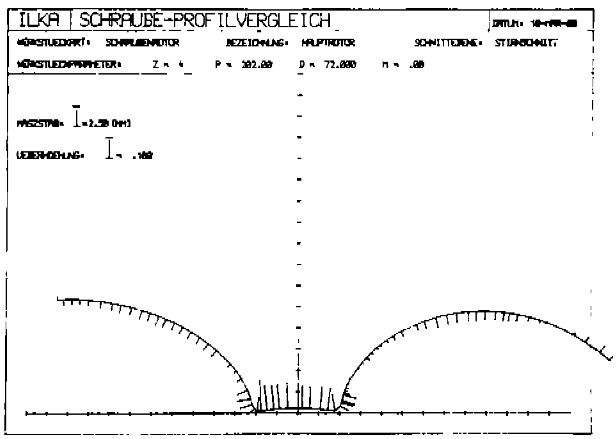


Fig. 12 - Graphic representation of the comparison between the calculated and measured profile of the main rotor

5. CONCLUSIONS

The system of computer programs described here is based on the application of CAD-techniques and has been worked out within 5 years period. It has been proved that the advantage of the utilisation of CAD-technology is greater the more complex the process is considered to be starting with research and development and ending with the process of manufacturing.

As a result of the research work done, a method has been developed making it possible to manufacture screw compressors below a displacement of 100 m^3/h.

The method to machine the rotors in two steps, first through milling, and second through grinding, has proved to be a very good one. The screw compressors manufactured so far have shown a COP which is the same as that of reciprocating compressors of the same size.

The introduction of CAD-technique has shortened the process of research and development, lowered the costs, at the same time improving the quality of the products as well as efficiency.

REFERENCES

1. R. Bernhardt: CAD/CAM-Anwendungsbeispiele aus der Praxis (Practical examples of CAD/CAM). VDE-Verlag GmbH, Berlin-Offenbach 1984.
2. R. Schüler: Rechnergestützte Entwicklung von Schraubenrotorprofilen (Computer-assisted development of profiles of screw rotors). VDI-Berichte 521. Schraubenmaschinen, pp. 137-161.
3. I.W. Wiss: CADD and the mechanical engineer. Heating-Piping-Air Conditioning, (1983)5, pp. 41-47.
4. F. Krause: Fertigung der Zahngeometrie von Schraubenrotoren (Manufacturing of the geometry of screw rotors). Luft-und Kältetechnik, 32(1983)4, pp. 196-199.
5. W. Lotze, A. Koßler: Einbindung von Drehkoordinaten in Koordinatenmeßgeräte (Introduction of rotory coordinates into coordinates measuring devices). Feingerätetechnik, 31(1982)9, pp. 394-397.
6. A. Koßler: Untersuchung der Fertigung von Schraubenrotoren mit Hilfe der Koordinatenmeßtechnik (Study of the manufacturing of screw rotors by means of coordinates measuring devices). Feingerätetechnik, 33(1984)9, pp. 405-407.
7. S. Nowotny: Erste Erfahrungen bei der Nutzung von CAD/CAM-Techniken am Beispiel der Entwicklung und Fertigung von Rotoren für Schraubenverdichter (Experiences with CAD/CAM-techniques used to develop and to manufacture the rotors of screw compressors). DKV-Tagungsbericht, 12. Jahrgang (1985), Aachen, pp. 189-201.

LA MISE AU POINT D'UN NOUVEAU SYSTEME DE PROGRAMMES DE CALCUL POUR LA GENERATION, LE CALCUL, LA VERIFICATION, LA FABRICATION ET LA MESURE AUTOMATIQUE DE PAIRES DE ROTOR HELICOIDAL POUR DES COMPRESSEURS FRIGORIFIQUES

RESUME: Des informations sont données sur un nouveau système de programmes de calcul destinés à la génération, le calcul, la construction et la vérification de la géométrie de profil de paires de rotor hélicoidal utilisées dans les compresseurs frigorifiques.

On décrit le modèle mathématique fondamental.

Basé sur la géométrie du rotor hélicoidal non selement le profil d'outil mais aussi les données nécessaires à la commande des machines-outils type CNC pour la fabrication des profils d'outil sont calculés.

Le système de programmes comprend également des programmes de calcul pour l'établissement de la comparaison des chiffres prévus avec les chiffres réels, c'est-à-dire la comparaison des coordonnées du profil de rotors hélicoidaux calculées avec les coordonnées réelles déterminées par des machines tridimensionnelles à mesurer des coordonnées.

Enfin des informations sont données sur les résultats et les expériences obtenus en vue de l'amélioration de la géométrie de profil de rotors hélicoidaux.

Summary:

It is reported on a new-developed system of computer programs to generate, evaluate, design and check up the profile geometry of pairs of screw rotors to be used within refrigerating compressors.

The basic mathematical model is described.

Based upon the designed screw geometry the shape of the tool profile as well as of data to be fet into numerically controlled machine tools to manufacture the tool profile is calculated.

The program system comprises programs as well to compare the real geometry of the screw rotor with the calculated theoretical profile by means of automatically working appliances which measures and process three-dimensional coordinates.

Finaly it is reported on results and experiences achieved by improving the profile geometry of pairs of screw rotors.